Effects of Surfactants and Observed Thermocapillary Motion for Laser Melting Physics

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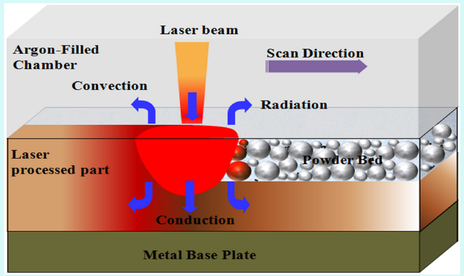
Motivation and Approach

We are interested in understanding the physics for 3D metal additive manufacturing; a process heavily influenced by surface tension, temperature, and metal composition. The heat from the laser and the surfactants within the metal affects the surface tension and thus the flow of the melt pool. Controlling these factors may be critical for quality of 3D printed parts or welded joints.

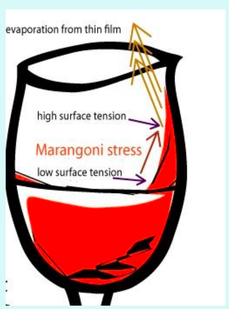
The newly developed fully implicit, high order, Reconstructed Discontinuous Galerkin (rDG) method is used inside the Arbitrary Lagrangian and Eulerian 2D and 3D (ALE3D) multiphysics simulation package developed at LLNL to accurately capture the surface tension effects. The code demonstrates capabilities of capturing complicated physics.



Representation of energy balance for the melt pool during additive manufacturing. (Yuan 2015)

Concentration Effects – Tears of Wine

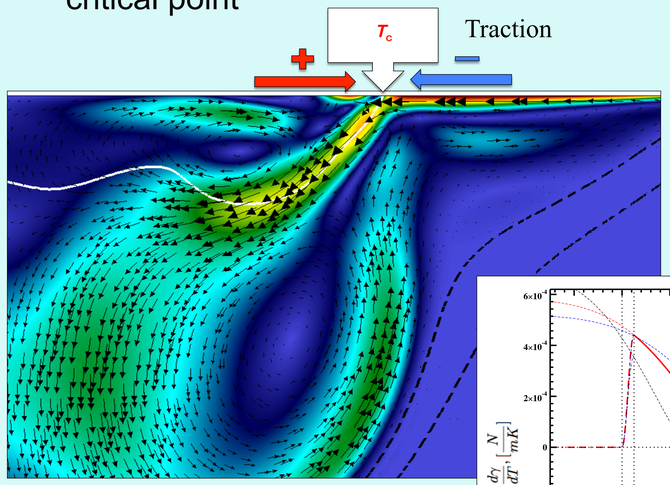
Water has a high surface tension, ethanol does not, as ethanol evaporates from the wine surface the water molecules increase the surface tension creating a gradient. The wine responds by climbing up the glass to reduce the surface tension.



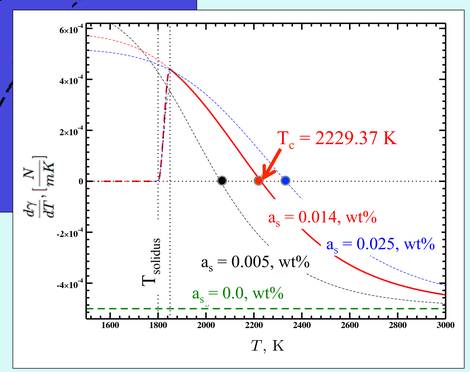
Representation of the Marangoni effect due to concentration differences in the fluid wine. (Wine Monopole, 2013)

Marangoni Flow

- Driven by surface tension effects
- Surface tension depends on temperature, its gradients, and chemical composition
- Surface thermocapillary action changes sign at the critical point

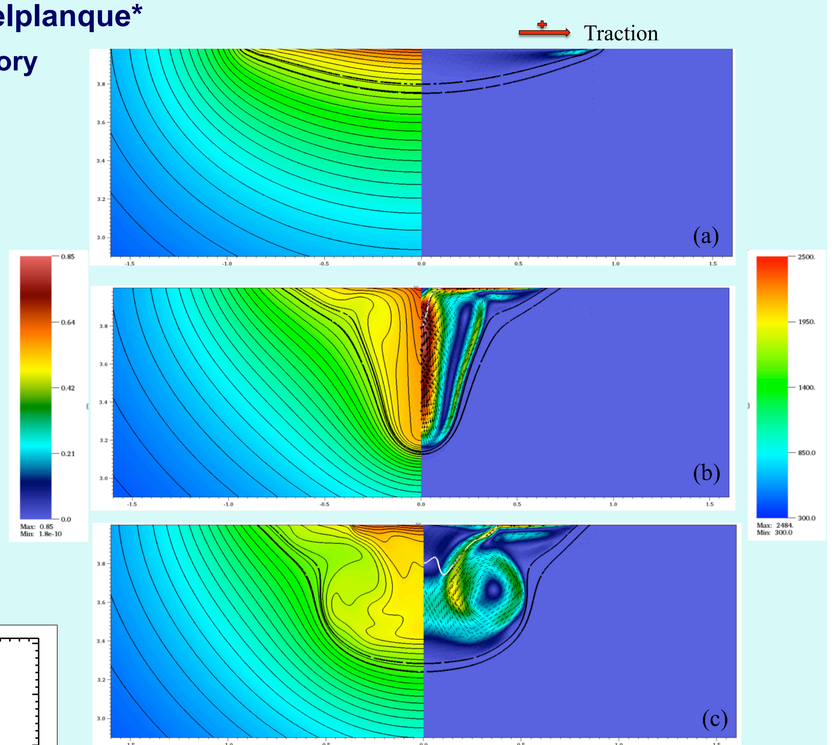


The flow field is dependent on mass gradient, critical temperature, and surface traction. The surface tension decreases with increasing temperature until the melt reaches the critical temperature, at which the surface tension changes direction (graph to right).



Results

We demonstrate that the flow is influenced by the addition of surfactants and the laser power (surface temperature). It is apparent that with no surfactant the critical temperature is not reached and a difference in traction direction does not occur. With surfactant introduced into the fluid the critical temperature is more quickly reached giving rise to the opposing vortical structures. Surfactants might influence the resulting microstructure, properties, and performance of a finished product. Without control of the Marangoni effect part defects could arise.



2D axis-symmetric temperature and velocity profiles for the Marangoni effect with (a) no surfactant and power 1200 W (b) surfactant 0.014% mass fraction and power 1200 W and (c) surfactant 0.014% mass fraction and power 1500 W.

Future Direction

Analysis of results will continue for a range of problem conditions including convergence studies, and understanding laser size and power. A soon to be available preconditioner for the rDG model will provide efficient simulation at high mesh resolution. It is also desired to determine the effect of surfactants more thoroughly by examining what occurs when the surfactants are not uniformly distributed throughout the simulation. Adding mass transport for the surfactant particles will give a more accurate picture of the true flow and surfactant influence.

References

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